Robotics in Manufacturing Technology Roadmap

November 2006

Prepared for

Energy Industries Of Ohio

Prepared by:

Energetics

Acknowledgement

This Technology Roadmap was prepared as part of a project entitled "Robotically Enhanced Advanced Manufacturing Concepts to Optimize Energy, Productivity, and Environmental Performance." Funding for this project was provided by the U.S. Department of Energy (Project #DE-FG36-05GO85046).

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Introduction

Background

American manufacturers are facing increased global competition, particularly from countries where labor costs are much lower than those in the United States. New technologies that improve manufacturing cost competitiveness – including those that increase productivity or reduce energy use – will help meet this challenge. Industrial robots, which have been in use since 1961, have the potential to make a greater contribution to productivity in manufacturing.

This *Technology Roadmap for Robotics in Manufacturing* is the result of a collaborative effort to assess the future of robotics in manufacturing. To gain industry input to the roadmap, a workshop was held in June 2006 with emphasis on the application of small lot and flexible robot systems in manufacturing. In this workshop, industry stakeholders outlined critical barriers to increasing the use of robots, and provided their thoughts on the research, development, and other activities needed to overcome those barriers. Contributors to the report are listed in Appendix A.

The Role of Robots in Manufacturing Today

Since the first industrial robot—essentially, a mechanical arm—received a patent in 1954, radical changes in global competition and advancements in computer technology have led the way for increased sophistication and capability of this technology. The addition of three more axes (pitch, roll, and yaw) that allow for extremely precise manipulation of a tool "hand," the addition of cameras, and the integration of artificial intelligence into governing software have all enabled more rapid and fine-tuned adaptation.

The robotics industry has grown to provide a wide range of robots for use in global manufacturing industries. Precise assembly, repair, demolition, and other crucial manufacturing steps can be accomplished efficiently, quickly, and at lower cost than human labor. This increased productivity has contributed to an annual increase in both the number of user industries and total robots shipped.

Since 1990, some applications of robots have enjoyed a cost advantage over human labor. Falling prices and increasing machine capabilities during this period dramatically decreased robot costs. In 2003, robots were being produced at a fifth of the cost of a robot built in 1990, with the same capabilities. In addition, hourly wages have greatly increased since 1990, particularly in the automotive industry, making robots even more cost-competitive [UNECE 2004].

The largest user of industrial robotics today is the automotive industry, which was responsible for about 50 percent of all domestic industrial robot purchases in 2004 [UNECE 2004]. Robots have been used since the late 1970s in car production for welding, painting, and assembly. Despite a recent downturn in the American car industry, auto parts producers are growing and driving a surge in robot orders, even when global automotive end producers are lightening their demand. Furthermore, growth in industries such as semiconductors, electronics, plastics, food, consumer goods, and pharmaceuticals assures the robotics industry an important place in worldwide manufacturing [UNECE 2004, IFR 2005]. Increased automation in these and other industries, such as off-road vehicles, appliances, aerospace, and metal fabrication, are also contributing to the increased use of robots.

Most industrial robots worldwide are used in welding and material handling or moving. As shown in Figure 1, these two tasks command 88 percent of all robotic activity, while other tasks like painting, sanding, and assembly filling make up the remaining 12 percent [Vincent 2006]. This range of tasks capitalizes on the advantages robots hold over human labor in high-volume and harsh manufacturing environments. Advances in technology are also beginning to allow complex, variable tasks to be conducted robotically.

In 2004, the majority of installed robots worldwide were multi-purpose articulated robots, accounting for 62.5 percent of sales [IFR 2005]. Other more specialized varieties make up the difference (see Figure 2). Asia has the largest market for industrial robotics. Japan and Korea, long the market leaders in robotics production and purchasing, are experiencing healthy expansion, although the robotics industries in North America and Europe are catching up. North American robot sales are expected to show strong growth through 2008, in part because of heavy Japanese automotive investment. Worldwide, the robotics industry is predicted to continue to grow through 2008 [Vincent 2006].

Investment in robotics research and development is stronger and more coordinated in Asia and Europe than in the U.S. Both Japan and Korea are implementing a national agenda in robotics, and both countries include robotics as critical growth engines. In Europe, a number of synergistic projects are bringing together industry and academia to further develop the robotics industry. The European Robotics Platform (EUROP) was recently approved at a level of $100 million per year. Similar initiatives do not exist in the U.S., and currently there is no national strategy that focuses on robotics. R&D outside of the U.S. has focused primarily on legged mobility, perception, and autonomy to support manipulation and

The Robot Advantage:

Accuracy, Speed, Increased Productivity, and Flexibility

Robots have several advantages over humans which make them excellent for working in environments such as assembly and manufacturing plants, hazardous mines, and in situations where the work is mundane or monotonous.

Productivity and Cost Benefits Robots can consistently produce more high-quality products than humans, never tire and can work nonstop without breaks, and do not require benefits. This translates into increased productivity, lower manufacturing costs, and in some cases, reduced use of energy and raw materials.

Doing Hazardous or Mundane Jobs Robots can do the work that no one else wants, such as mundane, dangerous, boring or repetitive jobs. Robots can take over in situations where work is extremely hazardous to human health, and can work with humans to make their jobs easier.

Consumer Benefits Robots can produce high quality goods quicker, which significantly reduces poorly-made goods and lowers the cost of goods to the consumer.

Figure 1. New Robot Sales Based on Expected Use [Vincent 2006]

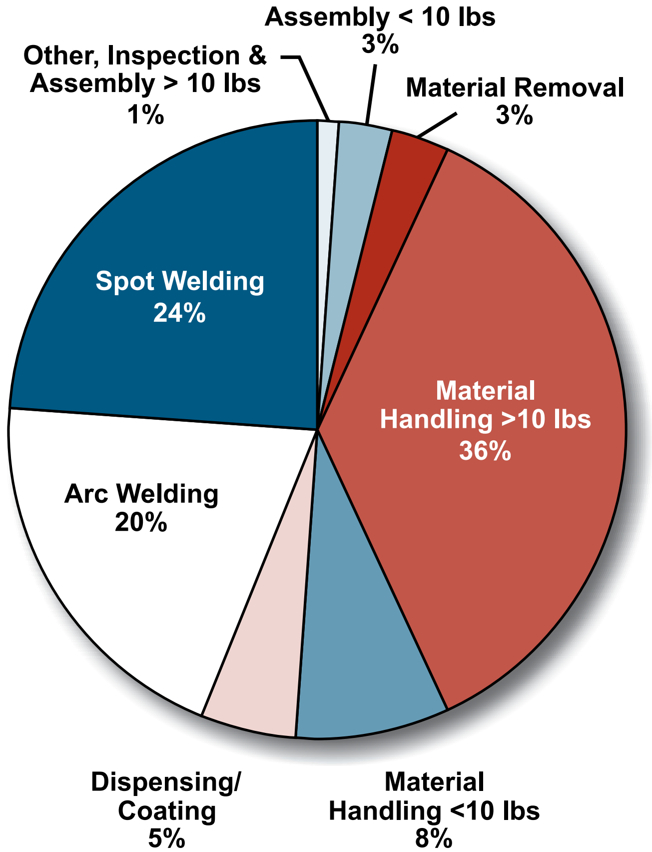
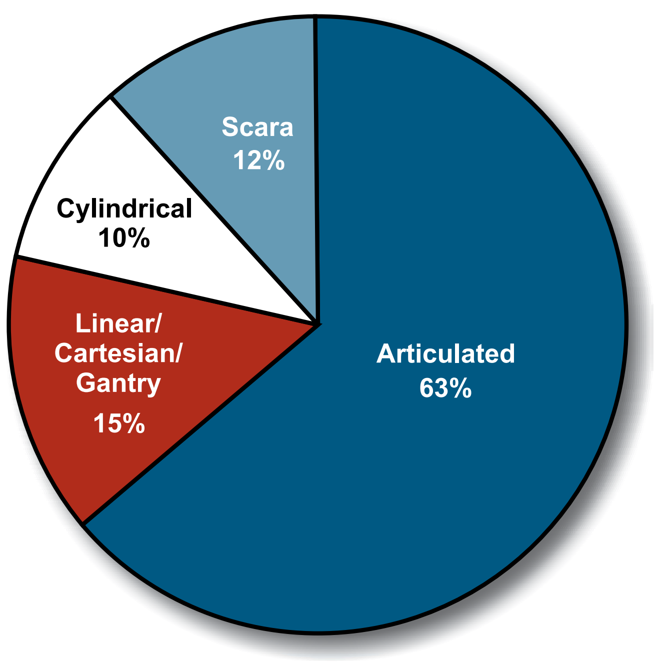


Figure 2. Worldwide Distribution of Newly Installed Robots, 2004 [IFR 2005]



other tasks. In the U.S., R&D has emphasized wheeled mobility, perception, and autonomy in navigation; the U.S. also leads in efforts to improve human-robot interaction [WTEC 2006].

Trends Impacting the Future Use of Robotics

Over the next 20 years, advances in robot technology are expected to continue. This and other factors will directly affect the growth of the robotics industry and robotic applications in manufacturing. Especially significant are those trends or factors that directly affect the affordability, marketability, and ease of deploying robots. Technical advances that increase task flexibility, technical capability, and improve ease of integration with the existing workforce could have a significant impact. Non-technical trends such as economic globalization, the availability of low-cost foreign labor, improved government incentives, and the increased availability of a well-trained workforce will also impact robot deployment.

Future Advances in Robotics

Flexibility

The development of more flexible robots that are able to multi-task will increase the usability and versatility of robotics, easing the adoption of robotics for a greater variety of tasks. Robots that are self-learning and self-modifying with high-speed response capabilities will be developed. Robot mobility, reconfigurability, and mass customization will increase, as will modularity and interoperability. This will enable robotics installations to be customized for size, payload, and capabilities, increasing potential applicability for manufacturing processes. Flexibility could enable manufacturers to use robots to

- take advantage of opportunities created by an aging, retiring workforce;
- meet increased demand for 6-sigma quality assurance; and
- handle the increasing number of microsystems requiring assembly.

Increased flexibility will make industrial robotics more attractive to small-lot manufacturers, one market that is still relatively untapped. Small businesses have long been deterred from purchasing robots due to high capital costs, the need for large production lines to make robotic investment prudent, and prohibitively complex operation and repair interfaces. However, small-scale manufacturing cells, user-friendly programming interfaces, and labor pressure arising from outsourcing are making robots more attractive to the small manufacturer.

Advanced Technical Capabilities

New materials such as electroactive polymers, shape-memory alloys, and materials emerging from developments in nanotechnology will facilitate the adoption of robotics in manufacturing. The incorporation of these materials into robotics systems will result in robots that are lighter, sensor-based, and more functional as an extension of the human, giving them greater applicability for manufacturing.

New technologies to improve robot sensing and general machine vision (optical sensors, tactile sensors), self-diagnosis capability, and higher intelligence controllers will enhance functionality. Wireless technology will also be integrated within systems, as will artificial intelligence, allowing more human-like motions and greater awareness of environment. Greater capabilities, mobility, and intelligence, all enabled by new technology, will continue to increase the attractiveness of robots for manufacturing. Robots with a higher degree of precision and faster adaptability to design changes will stimulate use in industrial applications. These improved sensory components and flexible manufacturing cells combine highly specialized robots in an assembly-line production scheme to contribute to the growth of potential applications for industrial robots.

Systems Integration/Human Machine Interface

The development of robotics systems with advanced sensor technology and cognitive algorithms will improve robot ability to interface with humans and other robotics. This could promote the use of robotics in some manufacturing applications, particularly those where humans and robots need to work side-by-side. Improved human-machine interface will allow an increase in distributed networking and control, while enabling robots to conduct complex tasks and understand the relationships between task endpoints (i.e., task ordering, connection, and priority). Improving the human machine interface will also allow easier programming integration and improved process control and functionality.

Non-Technical Trends and Drivers

International Competitiveness and Trade

As globalization increases, outsourcing of American jobs and movement of manufacturing overseas is becoming a more volatile issue. Low-cost labor in Eastern Europe and Asia continues to put pressure on countries with higher labor costs, particularly the U.S. Foreign producers have different safety, health, and labor standards, and are often able to take advantage of lower-cost labor and infrastructure. As a result, U.S. companies are actively seeking new ways to reduce labor costs and increase productivity to remain competitive. Installing and fully utilizing robotics can provide a low-cost means of increasing worker productivity and decreasing production costs. As foreign companies invest in new manufacturing equipment, U.S. companies will have to improve efficiency or replace entire assembly lines to remain competitive.

Companies are also seeking ways to compete with the less strict manufacturing and labor standards in overseas markets. U.S. labor unions are an important factor in this dynamic. While, there may be concerns about the effect of robotics on job security, robots may also be recognized for their ability to perform dangerous tasks and keep human workers from being injured.

Secondary fabricators and manufacturers (those who buy pre-assembled goods for the production of larger goods) are now more aggressively searching out low prices, regardless of what markets they have to enter to obtain the lowest price. This phenomenon is evident in increased offshore outsourcing and the trend of American companies to take advantage of cheap foreign labor. In the near future, as the economies of China and India grow steadily, there is likely to be greater investment in new manufacturing equipment in these developing countries. Due to the size and resources of these two countries, this increased investment could place greater pressure on the U.S. to maintain a domestic manufacturing infrastructure.

Sales of robotics are also impacted by downturns in industries that face heavy international competition, particularly automakers. The recent downturn in the automotive industry, for example, was accompanied by a significant reduction in robot sales to that industry –nearly 40 percent–in the first half of 2006.

However, sales in other industries (e.g., food and consumer goods, life sciences, pharmaceuticals, biomedical, others) increased during this time period, and this trend is expected to grow. New orders for assembly robots as well as for material removal robots (both non-automotive applications) experienced a 33 percent increase in growth over the same period, serving as further evidence that robotics are continuing to penetrate into new areas [RIA 2006].

Investment Drivers

A number of financial elements could also increase adoption of robotics in manufacturing. Robotics will continue to become more cost-competitive, requiring less initial capital investment. As technology advances, robotics will require less deployment time, decreasing delays in adoption of new robotic systems. Both factors could increase the return on investment (ROI) of robot implementation. The cost of labor (including wages and health care) is also expected to continue to increase, making robotics more attractive. In addition, the redeployment of existing robots is expected to create a market for inexpensive, used robots.

Financial incentives (e.g., tax, R&D incentives) could also increase the use of robotics in manufacturing by encouraging investments. Continued federal funding of R&D could help to drive down the cost of robotics systems, particularly through technology advances that are accelerated via federal initiatives (military combat systems, space applications, nanotechnology). In some cases, particularly where significant pre-competitive or high-risk fundamental research is required, a lack of federal R&D investment could result in lagging technology development.

Training, Education and Intellectual Capital

Trends in training and education are expected to play a role in the adoption of robotics in manufacturing. Education and curricula that supports the basic development of robotics expertise is available, as evident in the dramatically increasing levels of computer literacy among college and high school graduates. For over two decades, universities have been producing scientists and engineers with an avid interest in robotics, and these skilled experts have contributed to many exciting new advances in the field. However, limited training programs for those who work with robotics continue to hamper the use of robots in manufacturing.

Safety and Regulation

An increased focus on safety in human/machine interface is expected to lead to greater incorporation of safety systems into robotics software. Safety regulations will become an increasingly navigable reality for manufacturers and other users of robotics. Greater incorporation of safety features will in turn lead to easier robot deployment. The existence of jobs that are dangerous to humans and better suited for robots, also emphasize safety as an important factor in the potential adoption of robotics systems.

Barriers and Challenges to the Use of Robotics

While robotics has been demonstrated to be cost-effective in many applications, there are still a number of challenges to the more widespread implementation of robots in manufacturing. These challenges are both technological barriers and external issues related to finance, safety, and public perception. The most important of these have been identified and are listed in Table 1 (technical) and Table 2 (non-technical).

High Priority Technical Challenges and Barriers to Robotics in Manufacturing

Flexibility and Scale

The scale of a robotic system is a barrier to the expansion of robotics in manufacturing, since robots require a lot of energy and space on the plant floor in order to operate effectively. This requirement limits the specific tasks that robots can be used for, as size contributes to a lack of agility and dexterity, and energy requirements limit the size of a batch that robots can cost-effectively power-up and power-down to process. Robot size also limits the potential for utilizing more than one robot in close proximity to another, or for situating an operator and a robot in the same area.

The applications of robotics in manufacturing are further hindered by the large amount of time that they require for changing tasks, their limited reusability and their lack of flexibility for small-lot sizes and small batch manufacturing. As manufacturers consider investing

Table 1. High Priority Technical Challenges and Barriers to Robotics in Manufacturing

Flexibility
• Generally low level of flexibility, agility, and reusability • Lack of flexibility for small lot sizes (200 parts or less) • Limited compactness and lack of flexibility and dexterity
Systems Integration
• Limitations of inter-operability (systems integration, interface with ERP/MRP/production controls systems, and software) • Short robot life-cycle
Ease of Use and Human/Machine Interface
• Difficulty in programming effectively (requires highly trained personnel, extensive setup) • Lack of adequate robot/human interaction • Inadequate operator interfaces
Advanced Capabilities
• Lack of sophisticated, reliable machine vision and artificial intelligence • Complexity of applications vs. robot capabilities (clumsy, stupid)
Safety and Regulation
• Cost and burden of safeguarding systems • Inadequate or difficult validation of safety features
Standardization
• Lack of recognized universal standards for performance specifications • Conflict between standards and rapid adoption of new technologies

in robotics, these factors all limit robot ease of use and potential return on investment. If manufacturers are able to purchase one robot that can perform multiple tasks, be used successively in different areas, and operate at a high level of efficiency regardless of the batch size, then that manufacturer would be more inclined to integrate robots throughout their manufacturing processes. On the other hand, there is a capital investment required to integrate robotics into a manufacturing process. Limited robotic ability may result in a less attractive return on an investment; a lengthy transition period between tasks costs money in time, labor, and energy.

Human Machine Interface

Another key barrier for integrating robotic systems into manufacturing processes is the level of skill and training required to operate a robot and successfully integrate it into existing manufacturing facilities. Robots today are difficult to program effectively, hindering an organization's ability to maximize a robot's functionality and the return on investment. Robots currently require highly trained personnel and extensive setup time, which can make the implementation process costly. These factors not only limit an organization's return on investment, but also further the public perception that robots are hard to use and difficult to maintain.

Teaching a robot typically requires a more extensive set of skills than those held by a robot operator. Because of this and other difficulties in human/machine interface, robotic automation may require a higher-paid employee presence to ensure that all robots in a system function well together.

Systems Integration and Standardization

The lack of standardization in technology is another barrier to expanding the use of robotics in manufacturing. There are a variety of control languages involved in both human/machine integration and systems integration. Confusion over what control language a system should use draws energy and resources away from improving products, creating new and exciting applications and adding value to robotic systems. Standardization of programming languages could stimulate growth in robotics in much the same way that standard protocols and programming languages facilitated the entire growth of the internet, allowing companies to focus on value-added activities rather than fighting over whose language and protocols should be used.

Lack of technology standardization complicates the integration of arm, end effecter, and controller systems, and hinders plug and play capabilities between unrelated systems. It also complicates the potential interface between enterprise resource planning (ERP), manufacturing resource planning (MRP), and production control systems software.

The current lack of standardization in technology, policies, and robot functions leaves an atmosphere of uncertainty for potential and existing users of robotics. Potential users face uncertainty when comparing robot suppliers, implementation plans, and safeguarding mechanisms due to the lack of performance specifications, technology standards, and technical guidance. Prospective buyers also face a complicated landscape when assessing the potential to integrate robots into their existing assembly lines or to incorporate the use of multiple robots. Existing users can expect complications when hiring new employees or training existing employees not familiar with their specific type of robot.

Advanced Capabilities

While robots are currently able to perform a variety of specific tasks, there is a lack of suitability for more complicated tasks limiting robot applications in other areas of manufacturing.

Table 2. High Priority Non-Technical Challenges and Barriers to Robotics in Manufacturing

Investment Issues
• Lack of U.S. R&D funding/initiatives • Short-term financial focus of private sector (expect a simple payback in 2 years) • High deployment costs • Inability to predict return on investment (ROI)
Training and Education
• Limits to capabilities of current workforce • Lack of skilled employees for robot maintenance and service
Public and Corporate Perception
Perception that it is difficult to: • Acquire and deploy robots • Successfully integrate robots in manufacturing • Communicate robot specifications based on existing tasks • Use robots without taking jobs from people

Machine vision is currently unsophisticated and unreliable and artificial intelligence capabilities are limited. Robots also have limits to their ability to adapt to new tasks like assembly or welding, and they lack the precision and sensors necessary for micro-assembly tasks. In addition, robots are not highly resistant to the hostile environment often found in manufacturing. These areas of limited function result in robots not being able to perform tasks in physical spaces with variable moving parts or spaces that are lacking close human control.

Safety and Regulation

Although human/robot cooperation is closer to becoming a reality, safety regulations continue to limit the use of robotics in manufacturing. Robots are not necessarily built with safety as a top priority. They currently require extensive protection for those who operate them and for anyone else working in the area. Because safety procedures need to be tracked by the Occupational Safety and Health Administration (OSHA) and validated by regulatory bodies, robots are generally required to be in enclosed areas to limit access and ensure that all safety regulations are met. As a result of these space demands, the presence of robots tends to severely impact the space available for other robotic systems and humans.

Another barrier is that no national robotics safety standard implementation guide currently exists, leaving potential users on their own to meet safety regulations. Complications surrounding safety and meeting national regulations have been an area that robot users have had to navigate with minimal guidance.

High Priority Non-Technical Challenges and Barriers to Robotics in Manufacturing

Investment Issues

Economic factors also limit the adoption of robotics by the manufacturing industry. Because robots can be expensive, manufacturers want to have a tangible return on investment or other financial benefit from the purchase of a robot. Institutions of all sizes often require a payback of initial costs in about two years. Due to high initial costs and continuing operating costs, an investment in robotics can take longer to pay its cost back in full. The cost of the system surrounding the robot, including the interface and safety measures, also drive up the price of a new installation. Operating costs are also high due to the costs associated with programming, powering, and maintaining robotic systems.

Users do not currently have the ability to accurately predict their return on investment while accounting for the cost of training, system integration, upgrading a robotic system at a later date or replacing parts. New users also do not have the benefit of having knowledge of the best robotic system for their specific automated manufacturing needs. A complicated decision process can slow procurement and may require valuable personnel and financial resources.

A lack of connection sometimes exists between manufacturing needs and corporate R&D investment. Manufacturing efficiency and productivity may benefit greatly from more R&D. However, the inability to properly communicate the real benefits to management can result in corporate investments directed more toward developing new products or applications rather than lowering the costs of manufacturing existing products.

Another financial barrier is the general lack of funding for robotics research in the U.S. when compared with other countries. This lack of government support and limited investigation into new technologies and applications slows the development of safer, more adaptable robots.

Training and Education

The lack of personnel with robotics expertise within most manufacturing facilities is another barrier to the growth of robotics in this sector. Programming or teaching robots typically requires different skills from those of a machine operator. Employees with this training or education are in short supply despite a strong demand. Robots are useless without a skilled human able to train, operate, and service them. These issues of education and experience overlap with investment barriers, as employees with advanced skills require higher pay.

The barrier of an untrained workforce is also due to a cultural fear of technology, inadequate education programs, and impediments from unions and regulators. The current labor pool is neither comfortable with robots nor able to utilize their technology effectively. The result is a lack of understanding of opportunities for robots to provide an advantage and increase efficiency. Until this type of knowledge is plentiful, inadequate training and education will continue to be a barrier to expanding the use of robotics in manufacturing.

Public and Corporate Perception

Perception and communication issues also surround the adoption of robotics by the manufacturing industry. Manufacturing is perceived as simple labor that provides jobs to millions of Americans, while robots are often seen as threats to those jobs or potential replacements for humans in the manufacturing process.

Internal communication barriers limit the use of robotics in manufacturing. Developing robot specifications in relation to specific tasks and user requirements is a very difficult task and requires a high level of expertise. It is also difficult to assess new applications for robots beyond their initial intended use.

On the organizational or corporate level, many managers believe that robotics would be impossible to implement in their facilities, or they question the financial benefits tied to robotics. Another commonly held belief is that robots are not available quickly and require thorough study and planning before purchase and implementation. Also, managers may not envision any advantages in quality control from robots as compared to less expensive labor overseas. These barriers of perception limit the extent to which robots are pursued. When robots appear too complicated or a threat to jobs, they may not be considered an option.

Research and Development and Other Activities

Outlined below are activities that are needed to expand the use of robotics in the manufacturing sector, organized into technical research and development and non-technical activities. The six activities most likely to make the largest impact on the application of robots in manufacturing are outlined in more detail in *Activity Action Plans* shown later in this section. A list of acronyms used in these plans is provided in Appendix B.

High Priority Research and Development

Technical activities are oriented towards specific technology goals achievable through R&D. Table 3 summarizes the high priority technical activities identified as necessary to increase the deployment of robots in manufacturing.

User Interface and Ease of Use

The complexity of training a robot and integrating it into an existing manufacturing process remains a formidable barrier to the increased use of robotics in manufacturing. The development of a simple user interface and enhanced connectivity between robotic systems and other equipment would simplify the human/robot interface. This can be accomplished through R&D on interface templates, electrical, mechanical, and communications technology. Supporting R&D in software engineering and programming should also be pursued, as should programming-by-demonstration and integrating radio frequency identification devices (RFID) into robot design to make them more flexible and responsive. The development of robotics systems with advanced sensor technology and cognitive algorithms will also improve robot ability to interface with humans and other robotics.

Improved human/machine interface will result in greater ease of use and fewer skill requirements for robot operators. Making robots easier to control will increase the potential for

Table 3. High Priority Technical Research and Development

Ease of Use
• Develop simple user interface • Enhance robot connectivity to other equipment • Develop user-friendly software
Sensor Integration & Machine Vision
• Conduct research on machine learning methods • Integrate advanced sensor technology into robots • Improve intelligent grips
Standardization
• Assemble a private/public sector steering committee to assess standards for reproducibility • Outline standards for interface, software, and hardware • Build framework for technical standards and software standards
Safety Platforms and Guidelines
• Clear safety guidelines • Flexible risk analysis and supporting R&D in human/robot safety

distributed controls and completion of complex tasks. Improving sensor function has the potential to improve human/machine interface by allowing robot controls to be oriented more towards programming by demonstration, where a robotics system gathers information while an operator completes a task and then duplicates the same task. Improving human machine interface will also allow easier programming integration and improved process control. This will result in reduced training requirements, allowing operators to train robots themselves rather than requiring a more expensive, highly qualified robot specialist.

Sensor Integration and Machine Vision (R&D)

To further improve the flexibility of current robotics technology, the industry must pursue research and development in the areas of sensor integration and machine vision. This research and its resulting technology developments will enable robotics to play a larger role in the automation of advanced assembly processes through enhancing the ability of robots to navigate products and assembly lines. The robotics industry would benefit greatly from investments in new research paradigms in pursuit of the capabilities and flexibility necessary for robots to play an increased role in assembly processes.

Other areas requiring further research include improving motion control programming; embedding sensors in tooling and grippers to measure force, temperature, visuals, and touch; and enhancing robots and end of arm tooling (EOAT) with wireless controls and connectors. All of these research areas will enhance flexibility and allow robots to follow more precise instructions and expand their range of abilities to a broader variety of manufacturing tasks. These technologies will also enable robots to respond to changes in their surroundings and in the materials involved in their manufacturing tasks. Research and development in these areas will enhance robot adaptability and reduce the need for constant human supervision.

Standardized Robot Controls, Programming Languages and Operating Systems

Developing greater standardization will ease the integration of arm, end effecter, and controller systems, and improve interoperability between unrelated systems. Greater standardization in the robotics industry could be achieved by empowering or creating a steering committee group to develop a means to measure standards for reproducibility and repeatability. Early efforts will be needed to standardize a programming language for simulation and robot operation. A common, non-proprietary operating system and operating interface should be established to enhance plug and play opportunities between unrelated robotic systems, and even create interface opportunities for ERP, MRP, and production control systems and software. This effort should facilitate the growth of the robotics industry as a whole, allowing companies to focus on adding value to products and applications, rather than competing over whose language and protocols should be used.

Standardization will also enable robots to better integrate with other robots and existing manufacturing processes through simple, easily replicated steps. Standardization will also enable robot operators to gain maximum value out of their existing robot experience, regardless of the model or manufacturer that they have worked with in the past. Additionally, standardization will provide more certainty to potential robot users when comparing robot suppliers, implementation plans or safeguarding procedures.

Better integration between robots will also enable robotic systems to perform more thorough self-diagnosis of fault conditions and operate more efficiently with their surrounding systems. System managers will be able to take advantage of greater drop-in, plug-and-play functionality, which helps to maximize a robot's functionality and return on investment,while reducing personnel costs.

Safety Platforms and Guidelines

Developing clear safety guidelines will reduce the burden on robot users to develop and maintain extensive protection measures for their employees. Safety guidelines will also lead to a more streamlined process of robot deployment. These guidelines will be established through a joint effort by safety organizations and the robotics industry and will result in the development of a technical safety platform.

This same partnership will also promote the development of inherently safe robots and work cells through conducting flexible risk analysis and supporting R&D in the area of human/robot safety. From these efforts, safer robots will be developed with more self-contained safety systems and inherently safe design features.

Project Title: Ease of Use & Intelligence

1 Key Objectives

- Identify suitable application
- Build structure/system suitable for developing this technology
- Build corresponding virtual system
- Establish registration and feedback between virtual and actual system
- Develop task level interface for recognition
- Develop task level interface for action
- Build automatic code generator for above 2 items
- Apply against conventional application and validate

2 Key Milestones/Schedule

Milestone	*Schedule*
• Suitably demonstrate program under conventional application	
• Program simulator conventionally and demonstrate success with corresponding code on system	(3 & 4)
• High school student can program system with less than XX (to be determined) minutes	(5)
• Demonstrate successful application from task level description	(6)

3 Enablers

- Funding
- Champion

4 Expected Benefits

- Ease of use
- Rapid deployment
- Reduced integration cost
- Reduced labor cost

5 Project Leader & Partners

- DOD
- DOE
- NIST
- NSF
- RIA

6 Next Steps

- Request for Proposals (RFP)

Project Title: Systems Integration & Standards

Key Objectives

- Distributed control architecture which supports plug and play
- Make integration a more intuitive process
- Standards for end effector integration
- Standards for sensor integration

Key Milestones/Schedule

Milestone

- Develop safety standards which support distributed control architectures (RIA)
- Standard interfaces documents (IEEE, ISO, etc.)
- Convince robot manufacturers to participate and have ownership

3 Enablers

- Single advisory and coordination group consisting of representatives from industry, government research and regulatory agencies, and universities

4 Expected Benefits

- Lower installation and programming cost
- Faster deployment within new industries and applications

5 Project Leader & Partners

- RIA
- NIST
- DOE
- DOD
- OSHA
- NIOSH
- FDA
- NIH

6 Next Steps

- Form coalition advisory group similar to USCAR or 21st century truck
- Solicit government and industry match funding

Project Title: Safety Constraints

Key Objectives

- Define a method of risk analysis that defines the safety risk
- Define risk analysis that impacts costs (weight, speed, soft surfaces, sensing, floor space)
- Develop the appropriate set of cost factors that achieve safe/low cost operations

Key Milestones/Schedule

Milestone

- Find or develop tool to do risk analysis
- Find or develop tool/tools to mitigate risk at the lowest cost

3 Enablers

- Risk analysis tool
- Cost optimization tool
- Technology development
  - Lightweight robotics
  - Appropriate speed robotics
  - Soft-surface technology
  - Sensing technologies
  - Floor space minimizing technologies

4 Expected Benefits

- Safe work environment
- Low cost manufacturing

5 Project Leader & Partners

- RIA
- OSHA

6 Next Steps

- Identify interested parties
- Evaluate/ develop tools

Table 4. High Priority Non-Technical Activities

Training, Education & Research Collaboration
• Create collaboration "Centers of Excellence" for universities, private industry, and government research • Identify champion or organizing body • Expand the expertise of existing and future domestic labor pool
Communications/Corporate Perception
• Focus on key points "Robots boost efficiency" and "Robots keep jobs at home" • Launch campaign at government level and at industry level • Develop and publish "case studies" on corporate experience with robot deployment
Market Stimulation
• Foster U.S. competitiveness in global robotics industry • Explore potential federally-supported tax and other financial incentives • Examine promising foreign technologies for adoption in U.S.

High Priority Non-Technical Activities

The non-technical activities identified as priorities are more focused on process. As shown in Table 4, these activities address major barriers in training and education, perception of robots, and market stimulation.

Training, Education and Research Collaboration

Increasing educational collaboration and training in robotics-oriented technologies will create a larger supply of skilled, experienced workers able to research, develop, and operate complicated robotics systems. This could be achieved by establishing collaborative "Centers of Excellence" to foster the development of robotics applications in the private sector and bolster the supply of qualified employees. These "Centers of Excellence" would offer free assistance to small companies and foster collaboration between industry, universities, and government to develop robotics solutions to manufacturing problems. To prepare students for advanced study, high schools should also incorporate education and simulations on robotics, programming, and other topics. On a larger scale, "Center of Excellence" collaborations could be extended globally to reap domestic benefits from knowledge about robotics technologies being developed in Europe and Asia.

The most effective way to start such collaboration and reach out to new stakeholders is through the efforts of a single champion or organizing body. This entity would develop relationships with other organizations and allow the robotics industry to pool resources, make strategic investments, and provide leverage to effectively communicate messages from the industry as a whole. An example of a strategic goal that could be pursued is the expansion of the programming community. Such an expansion could foster the skills necessary to use Programmable Logic Controllers (PLCs) or to change the perception of robots as "too complex" for manufacturing. Increased collaboration for education and other initiatives will result in a workforce that is familiar with robots and a manufacturing industry that is more likely to deploy robots.

Communications / Corporate Perception

The barriers created by the current public and corporate perceptions of robots could be addressed by national education campaigns, the development of case studies (including examples of successful robot implementation, maintenance ROI and programming in the manufacturing sector), and the organization of resource centers for robot users involved in manufacturing. Themes to be emphasized include:

- robots are solutions to many manufacturing inefficiencies
- robots can help keep jobs in the U.S.
- robots can increase U.S. manufacturing efficiency and help avoid the relocation of factories overseas

Addressing these issues will help to alleviate corporate concerns with investing in robotics systems. Far-reaching campaigns could focus on broad issues, while case studies could be used to tackle barriers surrounding robot implementation, costs, maintenance, and programming. Case studies should be published in manufacturing journals, mainstream business press, and other publications, describing user expectations, disappointments, and successful integrations. Forums could also be established for users to exchange knowledge with one another, allowing for organic communication between existing and potential robot users.

All of these communications initiatives could indirectly stimulate the increased deployment of robots in manufacturing by better informing corporate investors and providing a roadmap for robot deployment. Both robotics case studies and a national campaign should focus on the use of robots in new industries, with an emphasis on opportunities in manufacturing.

Market Stimulation

Stimulating the market for robotics in manufacturing will be achieved through both financial and policy measures. Tax incentives are one method of reducing the initial capital investment required from a manufacturer when deploying new robots. These incentives should be focused on rewarding users whose implementation of robotics leads to societal benefits, such as increasing worker safety or conserving energy. Other means of directing financial support towards the use of robots in manufacturing include loans from the Small Business Administration (SBA) which target automation, robotics or intelligent assist devices (IAD). One method of pursuing these incentives could be to contact legislative groups, such as the U.S. Congressional Competitiveness Caucus, to stress the capabilities of robots to increase domestic manufacturing efficiency.

Investment in robotics could be further sparked by fostering a national resolve for the U.S. to become more competitive in the global robotics industry. This effort would require campaigns to educate the government and private industry on the need for additional dedicated funding for robotics R&D development, and how robotics might contribute to U.S. competitiveness and keeping manufacturing jobs from moving overseas.

A survey of foreign robot technologies, their capabilities and applications, and their suitability for transfer to the U.S. could help to identify and stimulate penetration into new markets. Competitions could then be held among ”Centers of Excellence” to explore robot technologies suitable for a specific market, task or application.

Project Title: Collaboration & Knowledge Transfer Partnerships

Key Objectives

- Form collaborative partnerships to explain and enhance use of robotics in U.S. for competitive advantage
- Technical R&D
- Education-workforce skills/acceptance
- Address regulatory agencies (OSHA)
- Technology/knowledge transfer

Key Milestones/Schedule

Milestone	*Schedule*
1) Identify key industries/users that need competitive assistance; identify target market	6-10 mos.
2) Assess state of the art: successful applications vs. deficiencies	2-3 mos.
3) Identify short-falls	During #2
4) Call for participants to establish projects of work/specific needs	6 mos.
5) Group participants to tasks for each objective	6 mos.
6) Identify funding services participants/ associations/government	1 mo.
7) Formal project proposals	6-18 mos.
8) Run projects	2-3 years
Total	**5-7 yr cycle**

3 Enablers

- Initial starting team
- Industry associations
- Members
- Academia
- Suppliers

4 Expected Benefits

- Commercialization of enabling technologies
- <5 years—2-3 projects
- <10 years—10% industry participation would be optimal

5 Project Leader & Partners

- Industry (users and suppliers)
- Academia
- Government
- Industry associations - RIA

6 Next Steps

- Gather enablers to start Step 1

Project Title: Investment in Robotics R&D Funding

Key Objectives

- Identify areas needing R&D work
  - High return—best ROI (i.e., robotic surgery, assembly)
- Identify potential R&D resources
  - Academic programs
  - National laboratories
  - Small business
  - Research institutes
- Identify sources of funding
  - Government
  - Industry
  - Foundations

Key Milestones/Schedule

Milestone

- Identify champion(s) for key technical tasks
- Formulate/articulate plan for matching resources and funding
- Identify key players in emerging markets/applications

3 Enablers

- Associations
- Consortia
- Federal budget
- Contests
- Education
- User need/input

4 Expected Benefits

- New applications
- New markets
- Improved process
- Improved safety
- International competitiveness
- New collaboration

5 Project Leader & Partners

- NIST
- University robot programs

6 Next Steps

- Solicit R&D resources
- Identify targets
- Identify current sources of funding
- User needs conference

Project Title: Reducing Investment Risk, Part I

Key Objectives

- Develop standardized decision-making tool for process analysis to assist with specifying robotic systems with built-in flexibility in various plant applications (flow chart-qualitative)

Key Milestones/Schedule

Milestone	*Schedule*
• Establish working group of manufacturers and users	
• Develop system approach/tools, key attributes, etc., that define a group of applications	
• Programming and validation	
Total time:	**2 years**

3 Enablers

- Funding source
- Industry interest

4 Expected Benefits

- Avoidance of stranded assets
- General feasibility of use
- Better, more flexible system specification

5 Project Leader & Partners

- RIA (leader)
- Manufacturers
- System integrators
- Academia

6 Next Steps

- Post on public RIA website

Project Title: Reducing Investment Risk, Part II

1 Key Objectives

- Develop accurate cost model/template using a spreadsheet and quantitative analysis for:
  - Initial costs
  - Operating costs

2 Key Milestones/Schedule

Milestone	*Schedule*
• Establish working group to develop a model/template (include manufacturers and users)	
• Data acquisition	
• Model development	
• Model verification	
Total time:	**1 year**

3 Enablers

- RIA/federal funding
- Data input from manufacturers and previous applications
- Actual results from various companies

4 Expected Benefits

- More reliable ROI results
- Increased management confidence in investment

5 Project Leader & Partners

- RIA (leader)
- Manufacturers
- Academia

6 Next Steps

- Post template on public portion of RIA website

Project Title: Reducing Investment Risk, Part III

Key Objectives

- Develop/improve simulation and demonstration tools to improve confidence in a robotic installation; current simulation available only after purchase of system
- Customer ability to do modeling prior to purchase

Key Milestones/Schedule

Milestone

- Establish working group
- Decision on software platform
- Development of user-friendly model for purchaser use
- Model verification
- Model release

3 Enablers

- RIA
- Suppliers
- Funding source

4 Expected Benefits

- Improved confidence prior to purchase decisions
- Improved sales ability for suppliers due to increased

5 Project Leader & Partners

- RIA
- Supplier
- Simulation software supply

6 Next Steps

- TBD

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Appendix A: List of Participants

Robert Ballard, Robotic Workspace Technologies, Inc.

Lawrence Boyd, Energy Industries of Ohio

George Brown, MeadWestvaco Corp.

Nicholas Dagalakis, National Institute of Standards and Technology

Steve Dickerson, CAMotion, Inc.

Jeff Fryman, Robotic Industries Association

Leo Gruber, General Die Casters, Inc

Ralph Hollis, Carnegie Mellon University

Sarne Hutcherson, The Timken Company

Larry Keller, The Timken Company

Thomas Kurfess, Clemson University

Lonnie Love, Oak Ridge National Laboratory

Howard Mayer, Queen City Forging

Ian Mitchell, Consolidated Industries, Inc.

George Mochnal, Forging Industry Association

Wyatt Newman, Case Western Reserve University

Joseph Pack, The Timken Company

John Roemisch, FANUC Robotics America, Inc.

Nipendra Singh, S&A Consulting Group LLP

Herschel Smartt, Idaho National Laboratory

Joseph Stetter, SRI International

Charles Tolle, Idaho National Laboratory

Brian Valentine, U.S. Department of Energy

Gideon Varga, U.S. Department of Energy

Donald Vincent, Robotic Industries Association

Derek Wadsworth, Idaho National Laboratory

Appendix B: Acronyms Used in Action Plans

DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
FDA	U.S. Food and Drug Administration
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Standards Organization
NIH	National Institutes of Health
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
NSF	National Science Foundation
OSHA	Occupational Safety and Health Administration
RIA	Robotics Industry Association
ROI	Return on Investment
USCAR	U.S. Council for Automotive Research